UCRL-PROC-208689

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December 17, 2004

Workshop on X-ray Diagnostics of Astrophysical Plasmas
Cambridge, MA, United States
November 15, 2004 through November 17, 2004

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Fe XVII Emission from Hot, Collisional Plasmas

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Abstract.
The ratios of the Fe XVII $3s \rightarrow 2p$ transitions to that of the dominant $3d \rightarrow 2p$ transition measured in high-temperature tokamak plasmas are compared to solar and astrophysical observations. Good agreement is found, indicating that the collisional line formation processes active in opacity-free, low-density, high-temperature laboratory plasmas are a good description of those found in astrophysical plasmas.

The intensity ratios of the $3s \rightarrow 2p$ and $3d \rightarrow 2p$ lines in Fe XVII observed from the Sun and various astrophysical sources have not been reproduced by spectral modelling codes. For example, the ratio of the sum of the three $3s \rightarrow 2p$ lines commonly denoted $3F$, $3G$, and $3H$ (or $M2$) to the strongest $3d \rightarrow 2p$ line denoted $3C$ is predicted by the APEC model to be $I_{3F+3G+M2}/I_{3C} \approx 1.33$ at the temperature of maximum abundance for Fe XVII. The ratios typically measured in the Sun [1, 2, 3, 4, 5] or stellar atmospheres [6, 7, 8, 9, 10, 11, 12, 13] range from 2 to 3 with an average of $I_{3F+3G+M2}/I_{3C} \approx 2.4$, as illustrated in Fig. 1.

The reason for the discrepancy has been the object of much speculation. Measurements using a microcalorimeter and the NIST electron beam ion trap had resulted in excellent agreement between measurement and collisional-radiative models based on electron-impact excitation of selected levels [14]. The agreement with APEC was also excellent, as shown in Fig. 1. Because of the large discrepancy between their measurements and astrophysical and solar observations the authors speculated that processes not found in their measurement must play a role in astrophysical plasmas.

Using a microcalorimeter and the Livermore EBIT-II electron beam ion trap a different conclusion was obtained. As illustrated in Fig. 1, the Livermore microcalorimeter measurements showed no agreement with APEC. On the contrary, they showed good agreement with solar and astrophysical observations [15]. Additional measurements were conducted with a grazing-incidence grating spectrometer and with a flat-crystal spectrometer. These had been tested and proven reliable in many other experiments [16]. The grating and crystal spectrometer measurements confirmed the Livermore microcalorimeter results. Another set of measurements have been made using a second-generation microcalorimeter and the Livermore EBIT-I electron beam ion trap on Ni XIX, i.e., using a different calorimeter, a different electron beam ion trap, and a different element [17]. The results again confirm the Livermore calorimeter data of Fe XVII.

In order to test for collisional effects possibly not addressed in the Livermore and NIST electron beam ion trap measurements, we have analyzed the Fe XVII emission from tokamak plasmas, including the PLT, DITE, and JET tokamaks [18]. Like in the

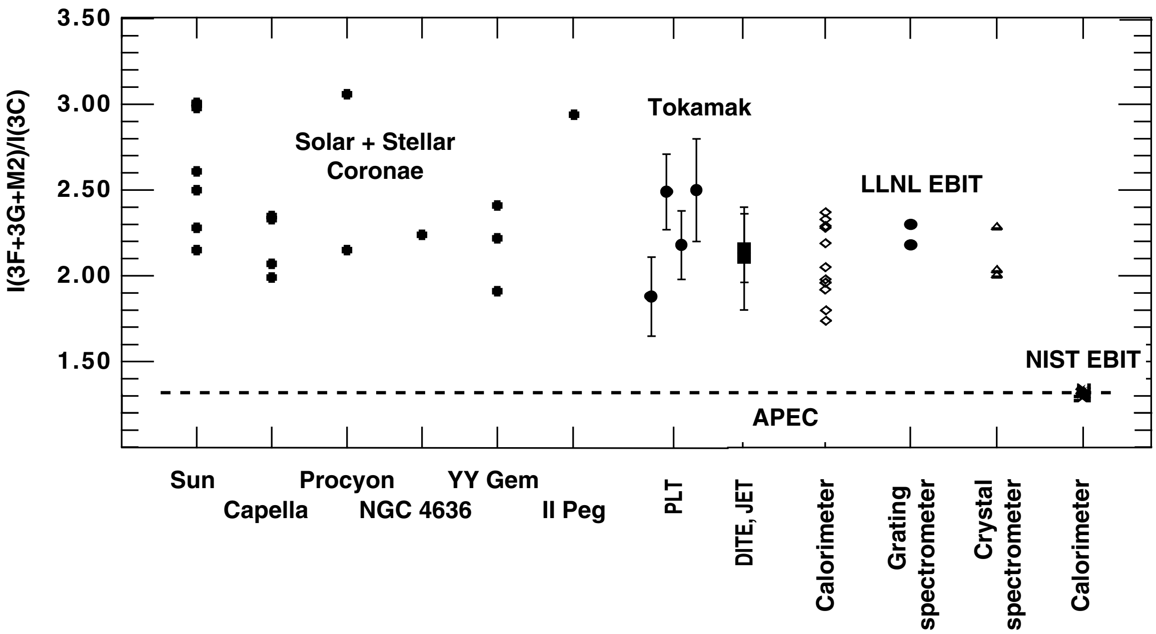

FIGURE 1. Comparison of the ratios of the sum of the three $3s \rightarrow 2p$ lines commonly denoted $3F$, $3G$, and $3H$ (or $M2$) to the strongest $3d \rightarrow 2p$ line denoted $3C$ measured in the laboratory and inferred from observations of various astrophysical sources and the Sun. APEC calculations shown as a dashed line are for an electron temperature of 432 eV.

Sun and stellar coronae, the Fe XVII emission from tokamak plasmas arises predominantly from those temperature regions where Fe XVII reaches its maximum abundance. Neighboring ionization states may also contribute, either by recombination or by innershell ionization. Tokamak plasmas are optically thin in the soft X-ray regime, and resonant scattering will not affect the line ratios.

We found that the tokamak data reproduced those from astrophysical sources, as illustrated in Fig. 1. We conclude that the collisional processes dominating in hot tokamak plasma are a good description of Fe XVII excitation. Moreover, the tokamak data also agree rather well with the ratios obtained in the Livermore electron beam ion traps for electron beam energies where indirect line formation processes involving neighboring ions do not play a role. These processes, however, appear to contribute at some level, as the tokamak ratios are on average higher than the LLNL ion trap data, in line with earlier determinations of the role of indirect line formation processes affecting neonlike ions [19]. Non-collisional processes need not be invoked to explain the Fe XVII emission. This means that the problems describing the astrophysical line ratios must lie with the collisional atomic data directly involving the Fe XVII ion.

Several high-resolution spectrometers have newly been installed on the National Spherical Torus Experiments (NSTX) tokamak [20]. These will observe the Fe XVII under various plasma conditions in upcoming experiments with the hope that further light will be shed on the Fe XVII problem.

ACKNOWLEDGMENTS

This work was performed under the auspices of the U.S. DOE by the University of California Lawrence Livermore National Laboratory under contract W-7405-Eng-48 and by the Princeton Plasma Physics Laboratory under contract DE-AC02-76CHO3073.

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